



Original Research

# Identification of Latent Classes of Motor Performance in a Heterogenous Population of Adults



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## KEYWORDS

Functionally-  
Impaired,  
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**Abstract Objective:** To determine classes of motor performance based on community deployable motor impairment and functional tests in a heterogeneous adult population.

**Design:** Sixteen tests of limb-specific and whole-body measures of motor impairment and function were obtained. Linear regression analysis was used to dichotomize performance on each test as falling within or outside the age- and sex-predicted values. Latent class analysis was used to determine 3 classes of motor performance. The chi-square test of association and the Fisher exact test were used for categorical variables, and analysis of variance and the Kruskal-Wallis test were used for continuous variables to evaluate the relationship between demographic characteristics and latent classes.

**Setting:** General community.

**Participants:** Individuals (N=118; 50 men) participated in the study. Quota sampling was used to recruit individuals who self-identified as healthy (n=44) or currently living with a preexisting chronic health condition, including arthritis (n=19), multiple sclerosis (n=18), Parkinson disease (n=17), stroke (n=18), or low functioning (n=2).

*List of abbreviations:* 6MWT, 6-minute walk test; 10MWT, 10-meter walk test; BBS, Berg Balance Scale; BBT, Box and Block Test; DGI, Dynamic Gait Index; LCA, latent class analysis; MMT, manual muscle test; MPPT, modified physical performance test; MVC, maximal voluntary contraction; PEGB, grooved pegboard test.

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*Intervention:* Not applicable.

*Main Outcome Measure:* Latent classes of motor performance.

*Results:* Across the entire sample, 3 latent classes of motor performance were determined that clustered individuals with motor performance falling: (1) within predicted values on most of the tests (expected class), (2) outside predicted values on some of the tests (moderate class), and (3) outside predicted values on most of the tests (severe class). The ability to distinguish between the respective classes based on the percent chance of falling outside predicted values was achieved using the following community deployable motor performance tests: 10-meter walk test (22%, 80%, and 100%), 6-minute walk test (14.5%, 37.5%, and 100%), grooved pegboard test (23%, 38%, and 100%), and modified physical performance test (3%, 54%, and 96%).

*Conclusions:* In this heterogeneous group of adults, we found 3 distinct classes of motor performance, with the sample clustering into an expected test score group, a moderate test score deficiency group, and a severe test score deficiency group. Based on the motor performance tests, we established that community deployable, easily administered testing could accurately predict the established clusters of motor performance.

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The ability to classify motor performance across populations is important for the evaluation, intervention, and prevention of disability. Motor capacity is an important element of the complex, highly prevalent, phenomenon of disability.<sup>1</sup> Commonly, disability can occur with a specific health condition (eg, stroke) or non-specific processes such as aging, which can affect motor systems. Although the underlying pathology contributing to motor performance may differ, there are often overlapping motor impairments across populations. For example, there is a loss of strength in various muscle groups as we age,<sup>2,3</sup> and individuals with stroke can experience weakness.<sup>4</sup> In addition to sharing the presence of motor deficits, there is variability in the degree to which each deficit is present for each individual and across populations. An individual may have a self-identified health condition and have no motor deficits. Conversely, an individual without an identified health condition may present with motor deficits. Thus, the presence and magnitude of motor deficits may be a stronger indicator of disability than health condition diagnosis. Despite the potential health and wellness ramifications, classification of motor performance in a generalizable way is poorly understood.

To classify a broad range of individuals, measures of motor performance that capture limb and whole-body performance are needed. Measurements of motor performance can be broadly categorized as measuring limb-specific or whole-body impairment and function. Impairment is defined as a loss of body function (eg, weakness).<sup>5</sup> Functional measurements assess the motor performance of a task involved in activities of daily living (eg, ascending stairs).<sup>5</sup> In addition to traditional clinical measures of function, there are a growing number of laboratory-based measures to assess motor performance. Notably, many laboratories use force transducers to measure the maximal contractile force of a given muscle group,<sup>6</sup> in addition to measuring strength through manual muscle testing.<sup>7</sup> There are many examples in the literature of the development of motor composite scores involving both measures of

impairment and function to capture a more complete picture of motor performance. However, the composites are usually specific to a special population.<sup>8</sup> To the best of our knowledge, no study has sought to use a broad range of impairment and functional measures to identify classes of motor performance across a heterogeneous population. An accurate portrayal of such could be used within community-based health settings, ultimately serving as easily deployed measures to better assess community motor performance profiles of diverse populations.

Therefore, the purpose of this study was 2-fold, namely to determine whether there are identifiable classes of motor performance in the adult population that are based on motor impairment and function tests and to determine whether there is a subset of easily administered community deployable motor performance tests that are able to predict class of motor performance.

## Methods

### Study sample

A total of 118 participants (42% men) were recruited in this cross-sectional cohort study. All data were collected between August 2015 and July 2017. To facilitate the aim of a larger study, quota sampling was used, recruiting self-identified healthy individuals (n=44) or individuals with a preexisting chronic health condition, including arthritis (n=19), multiple sclerosis (n=18), Parkinson disease (n=17), stroke (n=18), or low functioning (n=2). The inclusion criteria were community dwelling individuals between the ages of 18 and 90 years. The exclusion criteria were individuals reliant on an assistive device or those with a history of cognitive impairment or inability to follow study procedures. Study procedures were approved by the University's Institutional Review Board (approval no.: 13.129). All participants provided written informed consent.

## Motor performance tests

All tests for all participants were conducted by the same licensed physical therapist (RBB) during a single day. Testing took approximately 3 hours per person. Participants wore comfortable loose-fitting clothing and comfortable shoes. Responses to activities were monitored throughout, and participants were given frequent rest breaks to reduce the effects of fatigue. The following clinical and laboratory tests were used to assess motor impairment and function in the upper limbs, lower limbs, and whole body.

### Walking and balance function

The 10-meter walk test (10MWT) quantifies self-selected over-ground walking speed.<sup>9,10</sup> Individuals were asked to walk at their normal speed and faster than normal speed with time assessed between meters 2 through 8. The 6-minute walk test (6MWT) is a test of over-ground walking endurance.<sup>11</sup> Individuals were asked to walk as fast and as far as they could for the 6 minutes on a 50-meter looped course. A walking ramped intensity test was performed separate from the other walk tests, in which individuals were asked to walk for 3 minutes for each of their self-selected less than normal, normal, and greater than normal walking speeds. A stopwatch was used by the physical therapist to record the time. The Dynamic Gait Index (DGI)<sup>12</sup> is an 8-item test that measures balance during different over-ground walking and postural perturbations. The Berg Balance Scale (BBS) is a 14-item inventory that quantifies balance impairment in sitting and standing with static and dynamic perturbations.<sup>13</sup>

### Arm function

The Box and Block Test (BBT) assesses gross motor coordination of the hand and arm.<sup>14</sup> The grooved pegboard test (PEGB) quantifies dexterity of the fingers.<sup>15</sup>

### Performance of activities of daily living

The modified physical performance test (MPPT) is a 9-item inventory that assesses an individual's ability to perform several activities of daily living with varying complexity involving the upper extremity, lower extremity, and whole body.<sup>16</sup>

### Strength and spasticity

Manual muscle testing (MMT) is clinical assessment of isometric strength and muscle function<sup>7</sup> and was performed on the flexors and extensor musculature of the shoulder, elbow, hip, knee, and ankle bilaterally. The following tests were performed to quantify maximal voluntary contractile (MVC) strength and regulation of submaximal forces in the hand, arm, and leg. MVC grip strength was assessed using a hand-held dynamometer.<sup>a</sup> The order of left and right hand testing was randomized. A linear force transducer<sup>b</sup> was used to measure isometric MVC strength of the elbow flexors, hip flexors, and knee extensors. Data were acquired at 1000 Hz using Spike 2 software.<sup>c</sup> Force signals were filtered using a 0.01-second smoothing filter. Participants were encouraged to contract maximally and hold for 3 to 5 seconds. At least 3 trials were performed for each muscle group, and the peak value was used. After MVC testing, participants completed a 40-second submaximal (5% of MVC) isometric contraction for each respective muscle group. Visual feedback was provided

with instructions to hold the force steady. As a measure of an individual's ability to steadily regulate submaximal force, the coefficient of variation of force was calculated. The Ashworth Scale<sup>17,18</sup> measures spasticity, and the following muscles were examined: upper trapezius (shoulder elevation), middle deltoid (shoulder abduction), biceps brachii (elbow flexion), extensor carpi ulnaris and radialis (wrist extension), flexor carpi ulnaris and radialis (wrist flexion), iliopsoas (hip flexion), quadriceps (knee extension), tibialis anterior (ankle dorsiflexion), hamstrings (knee flexion), and gastrocnemius (ankle plantarflexion). The therapist manually evaluated resistance to passive stretch, and muscle tone was rated on a scale from 0 to 4. Based on this scale, 0 indicated an increase in tone and 4 reflected limb rigidity. Participants were asked to relax while muscle groups were stretched across their range over 1 second.

## Creating binary variables for each functional assessment test

Given a paucity of age and sex normative information across populations, we applied the following to delineate individuals falling within and outside of predicted values:

- (1) For MMT, a discrete variable (outside the limits/within the limits) was created based on whether participants were able to perform all items.
- (2) For MPPT, a discrete variable (outside the limits/within the limits) was created based on whether the individual scored at least a 3 on all items.
- (3) For other measures and using the self-identified healthy subsample, separate linear regression models with age and sex as independent variables was performed to obtain the expected performance for a healthy individual.
  - (a) Using the age- and sex-adjusted mean and variance, standardized z scores

$$z = \frac{y_{\text{observed}} - y_{\text{predicted}}}{\sqrt{RMSE}}$$

were calculated for all participants.

- (b) If a z score was within 1 SD of their age- and sex-expected score, an individual was categorized as "within limits" of the predicted value. If a z score was greater than 1 SD worse than their age- and sex-adjusted expected score, they were categorized as "outside limits" of the predicted value.

## Statistical analysis

Continuous variables were summarized using means  $\pm$  SD, and categorical variables were summarized as frequency and percentage. Linear regression models were used to determine the age- and sex-adjusted expected values for each functional test (except MPPT and MMT). After dichotomous limits of performance variables were created for motor performance tests, latent class analysis (LCA) was performed. LCA is a statistical method that considers the distinct patterns of responses over the functional test dichotomization and uses this to estimate the number of

homogeneous latent classes.<sup>19</sup> The chi-square test of association and Fisher exact test and analysis of variance and the Kruskal-Wallis test were used to evaluate the relationship between demographic characteristics and latent classes. The LCA (PROC LCA) and other statistical analysis was completed using SAS 9.4.<sup>d</sup> A *P* value of 0.05 was used to determine significance. A classification tree<sup>20</sup> was developed using binary recursive partition in R software (version 3.5.0),<sup>e</sup> and the *rpart* package<sup>e</sup> was used to predict the classes of motor performance.

## Results

### Sample characteristics

Participants in this sample were 57.6±17.8 years old (42% men, 88% White). Forty-four of the 118 participants were self-identified as healthy, with the remaining 63% self-identified with a disease (table 1).

### Summary of the motor performance tests

Table 2 summarizes performance based on health condition. Across all tests, healthy individuals generally performed the best. Individuals with stroke generally performed worse, compared with other groups. Table 3 summarizes individuals whose performance was outside the limits for each of the motor performance tests and across health conditions. Variability in performance within a given condition was noted. Because the determination of within or outside the

limits of performance was based on the subsample of healthy individuals, some healthy participants performed worse than expected based on their age and sex. Motor performance tests with the greatest number of participants whose performance was outside the limits as compared to their age- and sex-expected value were 10MWT (64%), PEGB (57.6%), and MVC of the hip flexors (57.6%). The DGI (8.5%) was found to be the test with the lowest incidence of outside the limits of performance.

### Summary of the LCA

Results produced 3 distinct classes, summarized in table 4. The 3 classes identified included individuals with minimal or no performance scores outside of the predicted values, accounting for 34.8% (n=41) of the sample. In this expected category, participants tended to perform at or above their age- and sex-predicted values on almost all tests. Specifically, 18 participants had no scores outside of the limits, 17 participants had 1 score outside of the limits, 4 participants had 2 scores outside of the limits, and 2 participants had 3 scores outside of the limits. For individuals who were classified as expected, the probability of scoring worse than expected ranged from 1% (DGI, MMT, Ashworth, BBS) to a maximum of 22.6% (PEGB). The second latent class identified was a group that was determined to have moderate deficiencies, including 42.4% of the sample. This group performed well on some, but not all, tests. Specifically, individuals in this group were more likely to perform worse than expected on the 10MWT, PEGB, MPPT, and maximum force test for hand grip. The third latent class, severe deficiencies, comprised 22.9% of the sample and included individuals who were more likely to perform worse than expected on tests. Specifically, individuals in this group had a 90% probability of performing outside the limits on the 10MWT, 6MWT, PEGB, MPPT, and MVC hips. The individuals classified in this group were more likely to perform worse than expected on 11 out of 16 functional tests.

### Ability of motor performance tests to distinguish classes

LCA also provided information regarding which tests were better in distinguishing latent classes. For example, the 10MWT, 6MWT, PEGB, MPPT, and MVC hips were good measures to classify individuals. Conversely, the DGI, BBS, and all 3 steady force measurements were not able to provide distinct grouping. Figure 1 illustrates the 3 latent classes using 3 tests that measure lower body function (10MWT), upper body function (maximum hand grip force), and whole-body function (MPPT).

### Demographic and performance characteristics of the 3 latent classes

Individuals in the expected group were significantly younger (48.6±16.9y) than those in the moderate deficiencies and severe deficiencies groups (61.0±16.7y and 64.7±10.2y, respectively; *P*<.0001) (table 5). Those in the severe deficiencies group were more likely to be in the obese body mass index category compared with other

**Table 1** Demographic characteristics of the study sample (N=118)

Characteristics	N	%
Age, y*	57.55±17.82	
Men	50	42.37
Body mass index*	27.56±5.89	
Race		
White	104	88.14
Black	7	5.93
Other	7	5.93
Marital status		
Single	31	26.27
Married	66	55.93
Divorced	12	10.17
Widowed	9	7.63
Highest level of education		
High school	18	15.25
College	57	48.31
Graduate degree	43	36.44
Self-reported health condition		
Healthy	44	37.29
Arthritis	19	16.10
Multiple sclerosis	18	15.25
Parkinson disease	17	14.41
Stroke	18	15.25
Low functioning	2	1.69

\* Variable is summarized as mean ± SD.

**Table 2** Summary of motor performance tests across health conditions (N=118)

Motor Performance Tests	Health Condition					
	Healthy	Arthritis	Multiple Sclerosis	Parkinson Disease	Stroke	Low Functioning
	(n=44, 37.29%)	(n=19, 16.10%)	(n=18, 15.25%)	(n=17, 14.41%)	(n=18, 15.25%)	(n=2, 1.69%)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
<b>Walking/Balance Function</b>						
<b>10MWT</b>						
Self-pace, m/s	1.6±0.2	1.2±0.2	1.3±0.4	1.4±0.3	0.8±0.3	1.4±0.0
Fast pace, m/s	2.5±0.4	1.7±0.3	1.8±0.6	1.8±0.4	1.1±0.5	1.9±0.4
6MWT, m	541.7±112.0	381.5±70.6	393.9±140.2	402.2±80.9	261.3±101.7	434.9±71.4
DGI	23.5±0.7	20.5±2.7	19.9±4.3	21.0±1.9	17.0±3.5	20.5±0.7
<b>Walking ramp test</b>						
<Normal speed, m/s	0.8±0.2	0.7±0.2	0.7±0.3	0.8±0.2	0.5±0.2	0.7±0.1
Normal speed, m/s	1.2±0.2	1.0±0.2	1.0±0.4	1.1±0.3	0.7±0.3	1.1±0.2
>Normal speed, m/s	1.6±0.5	1.2±0.3	1.2±0.4	1.3±0.3	0.8±0.5	1.2±0.2
BBT	55.8±0.7	52.3±3.5	51.7±6.0	52.8±2.9	44.6±5.7	54.0±1.4
<b>Arm Function</b>						
<b>Box and block test</b>						
Dominant hand	66.9±6.6	55.6±10.4	58.2±10.5	52.5±10.6	49.3±8.9	60.8±2.5
Nondominant hand	66.3±7.0	54.1±11.4	56.0±11.1	48.9±9.0	22.9±26.2	53.8±20.2
<b>PEGB</b>						
Dominant hand, s	90.0±12.4	127.8±31.7	105.3±23.0	135.4±36.6	135.0±36.3	108.3±14.5
Nondominant hand, s	96.2±18.8	142.3±42.9	120.7±31.6	150.1±33.1	138.2±32.0	148.7±57.7
<b>Performance of Activities of Daily Living</b>						
MPPT	32.6±2.4	26.0±4.3	28.1±6.2	27.9±4.1	19.1±5.3	31.5±2.1
<b>Strength and Spasticity</b>						
<b>MMT</b>						
<b>Maximum force</b>						
Right hand, N	376.3±93.1	241.3±87.9	292.4±84.2	267.3±104.2	236.5±112.7	239.6±54.8
Left hand, N	354.4±89.9	226.1±84.3	283.2±108.1	239.3±78.4	133.7±122.8	221.8±58.5
Right knee, N	318.8±95.9	180.9±72.6	248.5±81.7	209.1±72.2	226.4±81.3	164.1±43.3
Left knee, N	330.5±94.2	177.2±61.5	246.3±88.5	220.1±74.8	184.8±86.6	167.9±79.8
Right hip, N	387.7±102.4	204.0±66.8	316.3±111.5	251.7±81.3	229.7±78.4	197.9±47.3
Left hip, N	388.6±89.3	207.8±59.2	279.8±115.7	232.8±80.7	210.3±78.2	208.7±75.4
<b>Steady force</b>						
Right hand, N	1.0±0.6	1.3±0.6	1.1±0.7	1.3±0.6	3.4±7.8	1.1±0.5
Left hand, N	1.0±0.5	1.4±0.8	1.2±0.8	3.0±5.0	2.2±2.7	1.1±0.1
Right knee, N	3.5±1.4	5.9±2.1	4.5±1.6	5.7±2.6	6.0±3.2	4.0±0.4
Left knee, N	3.2±1.2	5.7±2.1	4.4±1.6	6.3±4.7	8.6±5.2	5.1±1.3
Right hip, N	4.5±1.6	6.4±1.8	5.3±2.6	6.8±3.6	8.6±6.8	3.4±1.6
Left hip, N	4.7±1.5	6.7±2.3	5.7±3.7	7.3±3.7	9.1±5.9	4.2±2.0
Ashworth Scale	0.0±0.0	0.0±0.0	0.1±0.2	0.1±0.3	1.9±2.0	0.0±0.0

**Table 3** Number and percentage of individuals who performed worse than expected for each motor performance test (N=118)

Motor Performance Tests	Overall		Self-Reported Health Condition												
			Healthy		Arthritis		Multiple Sclerosis		Parkinson Disease		Stroke		Low Functioning		
	(N=118, 100%)		(n=44, 37.29%)		(n=19, 16.10%)		(n=18, 15.25%)		(n=17, 14.41%)		(n=18, 15.25%)		(n=2, 1.69%)		
	N	%	N	%	n	%	n	%	n	%	n	%	n	%	
<b>Walking and Balance Function</b>															
10MWT	76	64.41	13	29.55	16	84.21	14	77.78	13	76.47	18	100.00	2	100.00	
6MWT	51	43.22	5	11.36	9	47.37	11	61.11	9	52.94	17	94.44	0	0.00	
DGI	10	8.47	0	0.00	2	10.53	2	11.11	0	0.00	6	33.33	0	0.00	
Walking ramp test	45	38.14	4	9.09	12	63.16	7	38.89	4	23.53	17	94.44	1	50.00	
BBT	12	10.26	0	0.00	0	0.00	3	16.67	0	0.00	9	52.94	0	0.00	
<b>Arm Function</b>															
Box and block test	53	44.92	7	15.91	10	52.63	8	44.44	12	70.59	15	83.33	1	50.00	
PEGB	68	57.63	9	20.45	14	73.68	13	72.22	15	88.24	16	88.89	1	50.00	
<b>Performance of Activities of Daily Living</b>															
MPPT	54	45.76	7	15.91	14	73.68	6	33.33	9	52.94	18	100.00	0	0.00	
<b>Strength and Spasticity</b>															
MMT	17	14.41	0	0.00	2	10.53	2	11.11	0	0.00	13	72.22	0	0.00	
Maximum force—hands	54	45.76	10	22.73	10	52.63	8	44.44	11	64.71	15	83.33	0	0.00	
Maximum force—knees	47	39.83	5	11.36	14	73.68	7	38.89	10	58.82	10	55.56	1	50.00	
Maximum force—hips	68	57.63	11	25.00	17	89.47	11	61.11	13	76.47	15	83.33	1	50.00	
Steady force—hands	13	11.02	2	4.55	1	5.26	2	11.11	1	5.88	7	38.89	0	0.00	
Steady force—knees	18	15.25	8	18.18	2	10.53	2	11.11	3	17.65	3	16.67	0	0.00	
Steady force—hips	17	14.41	8	18.18	0	0.00	5	27.78	2	11.76	1	5.56	1	50.00	
Ashworth Scale	16	13.56	0	0.00	0	0.00	2	11.11	2	11.76	12	66.67	0	0.00	

NOTE. Each motor performance test included dichotomized variables indicating whether individuals performed worse than expected on the respective tests.



**Table 4** Probability of being classified in the 3 latent classes for each below range motor performance test

Motor Performance Tests	Latent Class		
	Expected	Moderate	Severe
	(n=41, 34.75%)	(n=50, 42.37%)	(n=27, 22.88%)
<b>Walking and Balance Function</b>			
10MWT	0.219	0.798	0.995
6MWT	0.145	0.375	0.990
DGI	0.001	0.001	0.383
Walking ramp test	0.071	0.336	0.951
BBT	0.001	0.001	0.477
<b>Arm Function</b>			
Box and block test	0.192	0.437	0.871
PEGB	0.226	0.662	0.949
<b>Performance of Activities of Daily Living</b>			
MPPT	0.032	0.536	0.961
<b>Strength and Spasticity</b>			
MMT	0.001	0.041	0.570
Maximum force—hands	0.084	0.619	0.713
Maximum force—knees	0.044	0.492	0.760
Maximum force—hips	0.040	0.803	0.956
Steady force—hands	0.051	0.058	0.307
Steady force—knees	0.169	0.087	0.258
Steady force—hips	0.142	0.129	0.178
Ashworth Scale	0.001	0.043	0.529

NOTE. Each motor performance test included dichotomized variables indicating whether individuals performed worse than expected on the respective tests.

groups ( $P=.0003$ ). Although the individuals' self-reported health condition was significantly associated with the latent functional class, not all who self-identified as healthy fell within the expected group (13 of 44 healthy individuals) and having a disease or disorder did not automatically place an individual in the moderate deficiencies or severe deficiencies groups (10 of 74 individuals). A comparison of motor performance tests across each latent class is shown in [table 6](#). This table clearly shows the graded response on each motor performance test as the established classes move from expected to moderate deficiencies to severe deficiencies.

### Predicting latent classes by motor performance tests

From the 16 motor performance tests, a subset of 5 tests (10MWT, 6MWT, MPPT, BBT, and maximal hand grip force) were included in the tree building process. This subset of performance tests was selected for the classification tree analysis because they were identified in the LCA as being good measures to distinguish class of individuals. These tests were also chosen because of their feasibility of community deployment.

In the recursive partitioning analysis, the total sample ( $N=118$ ) comprised the "root" node of the classification tree. MPPT was the first selected predictor. Of the 64 participants who had a normal MPPT, the final predictor for determining their classification was their performance on the hand grip force. Specifically, 43 out of the 64 within

limits MPPT participants were classified as expected, and the remaining 21 were classified as moderate deficiencies. In comparison, for the 54 participants who had outside of limit scores for the MPPT, the next predictor was the 6MWT. The 17 participants who had a within limit scores for the 6MWT were classified as moderate deficiencies. However, the 27 participants who had an outside of limit score for the 6MWT were further divided by their performance on the BBT. Specifically, the 6 participants who had a within limit score for BBT were classified as moderate deficiencies, and the remaining 29 outside of limit scores for BBT participants were classified as severe deficiencies. A detailed summary of the final classification tree is provided in [figure 2](#).

Overall, the classification tree was able to correctly classify 101 of the 118 participants (85.56%). Specifically, 37 out of 41 (90.24%) in the expected and 24 out of 27 (88.89%) in the severe deficiencies groups were correctly classified. However, for the moderate deficiencies group, only 40 out of 50 (80%) of the participants were correctly classified, 5 of whom were misclassified as expected or severe deficiencies, respectively.

### Discussion

We sought to assess classes of motor performance in a heterogeneous sample using a broad range of clinical impairment and functional assessments and to evaluate whether established classes could be predicted by community deployable measures. The main findings from this study revealed that using LCA, 3 classes of motor

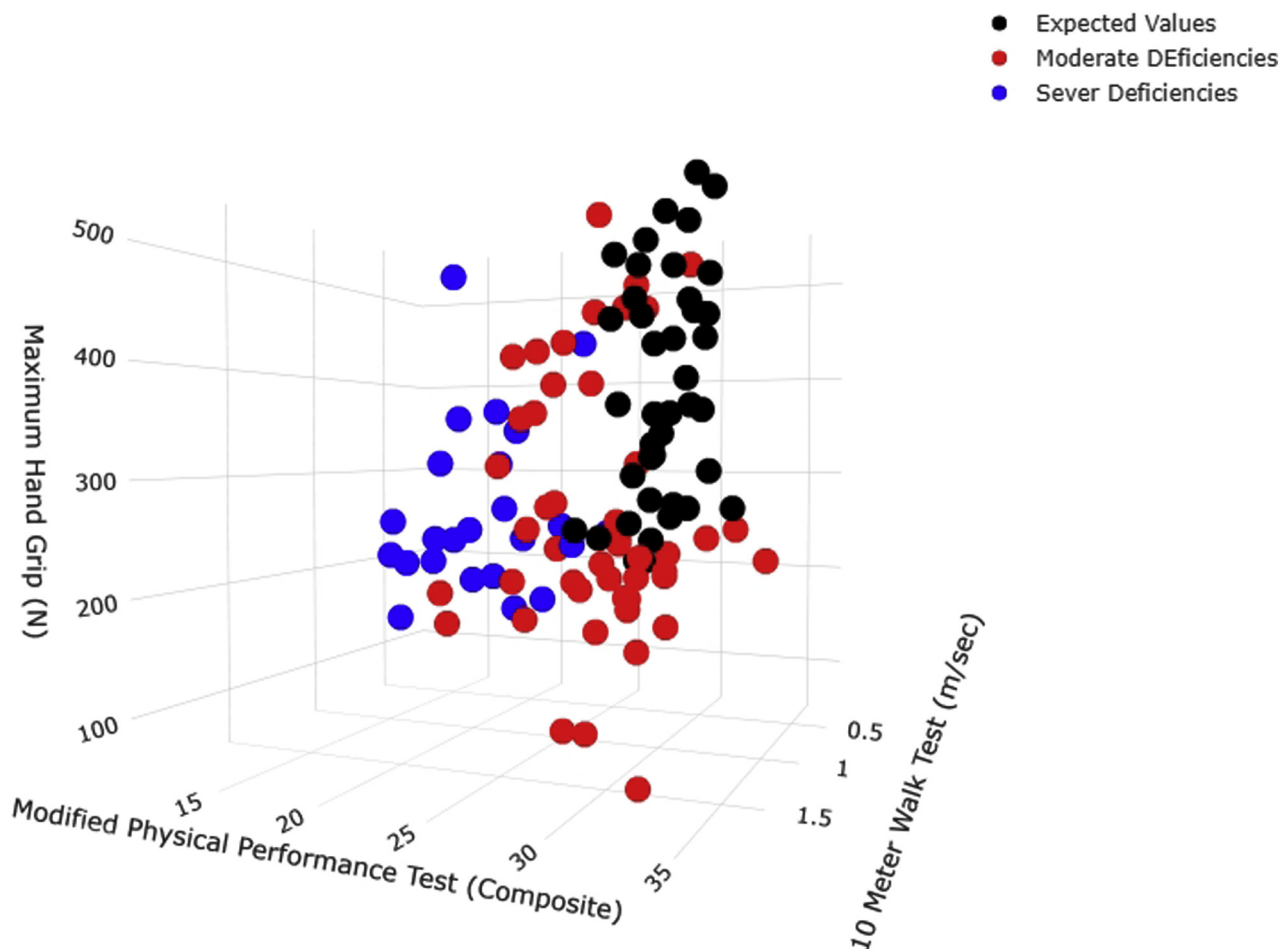


Fig 1 Three-dimensional illustration showing the 3 latent classes using the 10MWT, MPPT, and maximum hand grip force test.

performance (expected, moderate deficiencies, and severe deficiencies) were established in a heterogeneous adult population using 16 metrics of motor impairment and function. Furthermore, we found that a subset of the motor performance tests (10MWT, 6MWT, BBT, MPPT, and maximal hand grip force) were able to predict the established 3 classes of motor performance.

### A heterogeneous population can be classified by motor performance

Our results show clustering of measures that reveal distinct classes of motor performance across populations and demonstrate that some individual tests were better able to distinguish classes than others with a commonality of measuring whole-body performance.

Motor performance across a heterogeneous population can be classified into 3 groups in a graded fashion based on a group of motor performance tests. The 16 tests measured impairments in strength, balance, and coordination, as well as function in the upper extremity, lower extremity, and whole body. These findings are unique because performance of these tests is typically reported as they pertain to

a certain identified health condition. Importantly, as a composite, we were able to use scores to classify motor performance regardless of self-identified health condition.

When considered individually, there were certain motor performance tests that were better able to distinguish classes than others. We found the greatest number of participants outside the predicted range to be associated with the 10MWT, PEGB, MVC hip strength, and MPPT. A commonality of 3 of the motor performance tests that were better able to distinguish between the classes is an element of speed, involvement of both limbs, or whole-body performance, and quantification of function versus specific impairment. Walking speed and strength have been shown to be good distinguishers of class in previous studies classifying frail elderly<sup>21</sup> and mental health in individuals with hypertension.<sup>22</sup>

### Use of a group of easily deployable measures to predict motor performance

Several tests are needed to capture impairments and dysfunction that could affect physical activity and wellness in a heterogeneous population, and it is important to



**Table 5** Comparison of demographic characteristics across the 3 latent classes (N=118)

Characteristics	Latent Class						P Value
	Expected		Moderate		Severe		
	(n=41, 34.75%)		(n=50, 42.37%)		(n=27, 22.88%)		
	N	%	n	%	n	%	
Age, y*	48.59±16.90		61.04±16.71		64.70±10.20		<.0001
Sex†							
Female	22	32.35	29	42.65	17	25.00	.7475
Male	19	38.00	21	42.00	10	20.00	
Body mass index*	25.76±4.50		26.96±5.54		31.44±6.79		.0003
Race							
White	38	36.54	42	40.38	24	23.08	.6663
Black	1	14.29	5	71.43	1	14.29	
Others	2	28.57	3	42.86	2	28.57	
Marital status							
Single	15	48.39	12	38.71	4	12.90	.2615
Married	22	33.33	27	40.91	17	25.76	
Divorced	3	25.00	7	58.33	2	16.67	
Widowed	1	11.11	4	44.44	4	44.44	
Highest level of education							
High school	3	16.67	8	44.44	7	38.89	.2714
College	20	35.09	26	45.61	11	19.30	
Graduate degree	18	41.86	16	37.21	9	20.93	
Self-reported health condition							
Healthy	31	70.45	13	29.55	0	0.00	<.0001
Arthritis	0	0.00	15	78.95	4	21.05	
Multiple sclerosis	6	33.33	7	38.89	5	27.78	
Parkinson disease	3	17.65	10	58.82	4	23.53	
Stroke	0	0.00	4	22.22	14	77.78	
Low functioning	1	50.00	1	50.00	0	0.00	

\* Variable is summarized as mean ± SD, and the Kruskal-Wallis test was used to compare latent class.

† The Pearson chi-square test was used to compare latent class. All other comparisons were performed using the Fisher exact test.

deploy tests that best predict motor performance classifications. We showed that a subset of tests (6MWT, MPPT, BBT, and maximal hand grip force) were able to correctly classify 85% of individuals. The MPPT was the first predictor selected in the model, which likely reflects that the test has components that evaluate whole-body function. Although included in the algorithm, the 10MWT was not a predictor variable from the decision tree. This was surprising because the 10MWT is known to be an important predictor of overall function and wellness,<sup>23</sup> but it is likely that other tests that incorporated similar elements, such as the 6MWT and MPPT, diminished the predictive value of the 10MWT in this analysis.

### Health and wellness implications

The ability to classify motor performance using easily administered tests is important for the growing number of community health centers.<sup>24,25</sup> These centers serve as primary places to receive diverse health care needs, including preventative care, for millions of people.<sup>26</sup> Typically, these centers focus on reported perception of health and wellness or other medical indicators of health such as blood

pressure, without tests of motor performance.<sup>27</sup> Because motor performance can be an important contributor to mobility and wellness,<sup>28,29</sup> results from this study could be used to optimize community health centers assessments of overall health and guide health priorities in the community, as they relate to motor performance and function.

### Study limitations

This study used a cross-sectional study design, precluding causal relationship between functional assessments and functional class. Quota sampling methods reduced the generalizability of results, but quota sampling was necessary to address the primary objective of the funded research. A third limitation is the relatively small sample size, specifically with regard to the sample of self-identified healthy individuals. Because this healthy subsample was needed to determine the normative values for the functional assessment in lieu of unavailable published data, the sample may not be sufficient to provide robust estimates of mean and variances of the various functional assessments. Finally, we did not quantify other “nonmotor”

**Table 6** Summary of motor performance tests across the 3 latent classes (N=118)

Motor Performance Tests	Latent Class		
	Expected	Moderate	Severe
	(n=41, 34.75%)	(n=50, 42.37%)	(n=27, 22.88%)
	Mean ± SD	Mean ± SD	Mean ± SD
<b>Walking and Balance Function</b>			
<b>10MWT</b>			
Self-pace, m/s	1.60±0.17	1.37±0.22	0.86±0.32
Fast pace, m/s	2.51±0.43	1.93±0.39	1.11±0.45
6MWT, m	535.85±121.76	432.33±81.23	254.01±90.07
DGI	23.12±1.23	21.68±2.15	16.54±3.60
<b>Walking ramp test</b>			
<Normal speed, m/s	0.87±0.18	0.75±0.19	0.47±0.21
Normal speed, m/s	1.24±0.24	1.07±0.17	0.63±0.27
>Normal speed, m/s	1.59±0.49	1.34±0.26	0.74±0.33
BBT	55.51±1.27	53.67±3.35	45.19±5.42
<b>Arm Function</b>			
<b>Box and block test</b>			
Dominant hand	66.09±6.20	58.87±10.51	48.02±8.76
Nondominant hand	64.90±7.58	56.62±11.40	30.06±24.04
<b>PEGB</b>			
Dominant hand, s	90.75±12.77	114.39±28.91	140.47±36.77
Nondominant hand, s	98.53±22.96	129.93±35.54	148.69±40.62
<b>Performance of Activities of Daily Living</b>			
MPPT	32.93±1.54	28.84±3.87	19.29±4.87
<b>Strength and Spasticity</b>			
<b>MMT</b>			
Maximum force, N	39.83±0.54	38.46±2.03	37.04±4.52
<b>Right hand, N</b>			
Right hand, N	375.41±88.17	272.87±105.60	246.26±96.22
<b>Left hand, N</b>			
Left hand, N	356.47±93.80	254.03±96.44	170.00±114.88
<b>Right knee, N</b>			
Right knee, N	310.75±88.81	229.69±95.21	205.18±79.71
<b>Left knee, N</b>			
Left knee, N	317.09±87.69	240.77±96.45	167.99±79.14
<b>Right hip, N</b>			
Right hip, N	400.29±102.05	250.72±84.04	232.15±86.27
<b>Left hip, N</b>			
Left hip, N	389.15±90.02	252.01±93.19	202.65±75.90
<b>Steady force</b>			
<b>Right hand, N</b>			
Right hand, N	0.86±0.26	1.24±0.72	2.72±6.40
<b>Left hand, N</b>			
Left hand, N	0.98±0.53	2.04±3.08	1.68±2.07
<b>Right knee, N</b>			
Right knee, N	3.44±1.10	5.26±2.10	5.83±3.11
<b>Left knee, N</b>			
Left knee, N	3.35±1.22	5.41±3.43	7.30±4.63
<b>Right hip, N</b>			
Right hip, N	4.34±1.37	6.30±2.58	7.53±6.12
<b>Left hip, N</b>			
Left hip, N	4.71±1.32	6.61±3.31	7.97±5.44
Ashworth Scale	0.00±0.00	0.03±0.15	1.29±1.81

factors that could influence motor performance such as motivation or confidence.

## Conclusions

From 16 metrics of motor impairment and function using LCA, we established 3 distinct classes of motor performance (expected, moderate deficiencies, and severe deficiencies) in a heterogeneous sample of adults. We also found that a subset of motor performance tests, which are easily deployable in a community setting, were able to predict the 3 established classes of motor performance. Future studies are necessary to evaluate the feasibility of deployment of these tests within the community.

## Suppliers

- MSP 300; Measurement Specialties.
- LCM 300; Futek Advanced Sensor Technology Inc.
- Spike 2 software; Cambridge Electronic Design.
- SAS 9.4; SAS Institute.
- The R Project for Statistical Computing.

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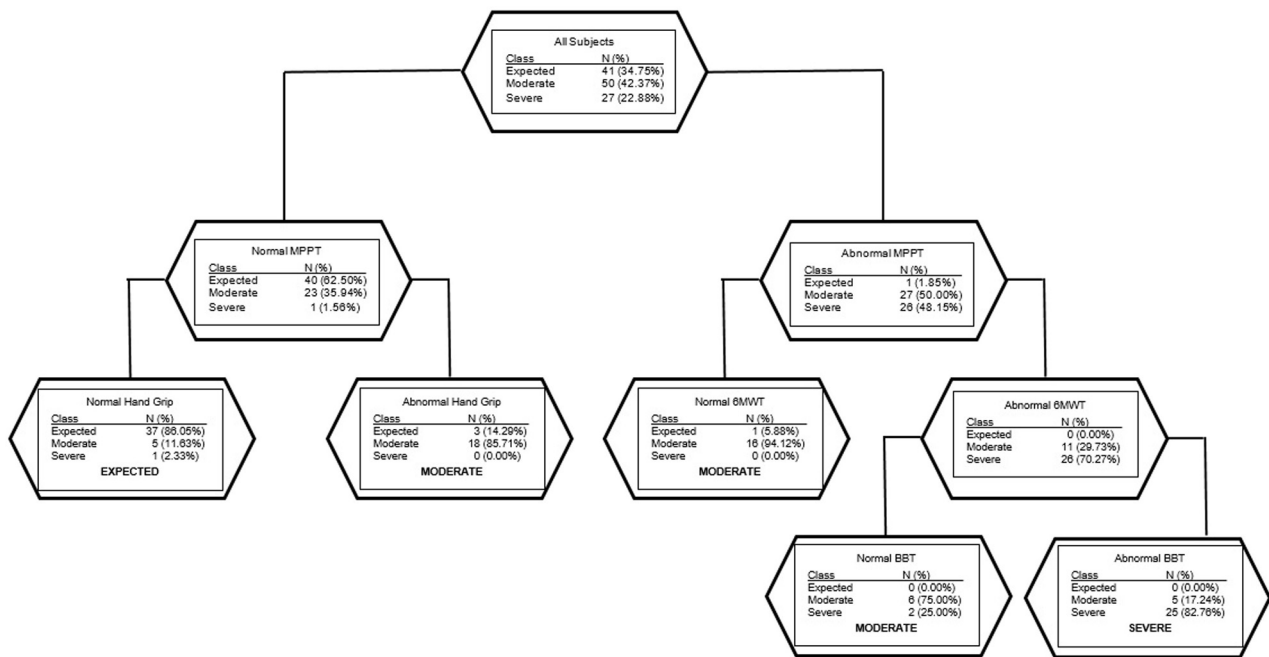


Fig 2 Classification tree.

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